8-2018

A Retrospective Cephalometric Growth Study of Sagittal Airway in Skeletal Class II Patients

Sue V. Kim

LOMA LINDA UNIVERSITY
School of Dentistry
in conjunction with the
Faculty of Graduate Studies

A Retrospective Cephalometric Growth Study of Sagittal Airway in Skeletal Class II Patients

by

Sue V. Kim

A thesis submitted in partial satisfaction of
the requirements for the degree
Master of Science in Orthodontics and Dentofacial Orthopedics

---

August 2018

Each person whose signature appears below certifies that this thesis in his opinion is adequate, in scope and quality, as a thesis for the degree Master of Science.

____, Chairperson
James Farrage, Associate Professor of Orthodontics and Dentofacial Orthopedics

____
Gregory W. Olson, Associate Professor of Orthodontics and Dentofacial Orthopedics

____
R. David Rynearson, Associate Professor of Orthodontics and Dentofacial Orthopedics

ACKNOWLEDGEMENTS

I would like to express my deepest appreciation to my committee members, Dr. Farrage, Dr. Olson, and Dr. Rynearson, for their constant encouragement and inspiring me to strive for excellence. They have constantly challenged me to think critically throughout the project.

Thank you to the American Association of Orthodontists Foundation (AAOF) for their enriching database, Sean Curry from AAOF, Kye Biedebach from Quick Ceph Studios, and Udo Oyoyo, my statistician, for helping me convert my data into valuable conclusions.

CONTENTS

Appendices

FIGURES

Figure Page

TABLES

Table Page

ABBREVIATIONS

SDB	Sleep-Disordered Breathing
OSA	Obstructive Sleep Apnea
ADHD	Attention-Deficit/Hyperactivity Disorder
CBCT	Cone Beam Computed Tomography
MRI	Magnetic Resonance Imaging
AAOF	American Association of Orthodontists Foundation
Po	Porion
Or	Orbitale
ANS	Anterior Nasal Spine
A-pt	A Point
U1	Maxillary incisor tip
B-pt	B Point
Pog	Pogonion
SP	Posterior limit of the soft palate, used interchangeably as 6A
TFH	Total Facial Height
1A-1B	Distance from most anterior to posterior limit of airway, along line perpendicular to Orbitale Vertical through ANS
2A-2B	Distance from most anterior to posterior limit of airway, along line perpendicular to Orbitale Vertical through A-pt
3A-3B	Distance from most anterior to posterior limit of airway, along line perpendicular to Orbitale Vertical through U1

4A-4B	Distance from most anterior to posterior limit of airway, along line perpendicular to Orbitale Vertical through B-pt
5A-5B	Distance from most anterior to posterior limit of airway, along line perpendicular to Orbitale Vertical through Pog
6A-6B	Distance from SP to posterior limit of airway, along line perpendicular to Orbitale Vertical through SP
ICC	Intraclass correlation
ANCOVA	Analysis of co-variance

ABSTRACT OF THESIS

A Retrospective Cephalometric Growth Study of Sagittal Airway in
Skeletal Class II Patients

by

Sue V. Kim

Master of Science, Graduate Program in Orthodontics and Dentofacial Orthopedics
Loma Linda University, August 2018
Dr. James Farrage, Chairperson

Purpose: The study retrospectively determined the average sagittal pharyngeal airway widths in Class II males and females between 7 to 16 years of age and changes in sagittal airway with increasing age. Additionally, this study determined whether average airway differs between gender at each age and compared the average airway widths in relation to increasing age between Class I and II patients.

Materials and Methods: Longitudinal cephalograms were digitally traced for 38 untreated subjects (23 males, 15 females) from age 7 to 16 with skeletal and dental Class II patterns. These records were previously taken through growth studies conducted between 1930-70s. Six horizontal lines perpendicular to Orbitale Vertical were traced through the following landmarks: anterior nasal spine (1A-1B), A-point (2A-2B), upper incisor tip (3A-3B), B-point (4A-4B), pogonion (5A-5B), soft palate tip (6A-6B). The intersections of these planes with the anterior and posterior limits of the airway were measured.

Results:

Class II: Males had more sagittal airway width, ranging from 2-8mm more than that of females at 1A-1B, 2A-2B, 4A-4B, 5A-5B, and 6A-6B (*P*=0.00-0.04). There was a significant increase in sagittal width from 7 to 16 years of age at 1A-1B for females (*P*=0.02) and 5A-5B for males (*P*=0.00).

Class I vs. II: While Class I females had more significant airway width at 3A-3B and 5A-5B than Class II females at age 11 and 12, respectively, the vice versa was true at 4A-4B at age 12. Class II males had more airway width at 1A-1B, 4A-4B, and 5A-5B of 1-7mm more than Class I males (*P*=0.00-0.05). No statistical difference was found in change in airway with increasing age between Class I and II patients.

Conclusions: Class II males had more airway width of 2-8mm more than that of Class II females at 1A-1B, 2A-2B, 4A-4B, 5A-5B, and 6A-6B (*P*=0.00-0.04). Class II males had more airway width at 1A-1B, 4A-4B, and 5A-5B of 1-7mm more than that of Class I males (*P*=0.00-0.05). Sagittal airway widths increased by a few millimeters in Class I and II patients with increasing age from 7 to 16.

CHAPTER ONE

REVIEW OF LITERATURE

Interest in pharyngeal airway research has steadily increased in the past few decades as clinicians have begun to appreciate the effects respiratory function has on craniofacial growth and development. According to Ceylan et al., Balters' philosophy suggests that a posteriorly-positioned tongue obstructs the pharyngeal airway leading to the formation of Class II malocclusions. Conversely, an anteriorly-positioned tongue leads to an overdevelopment of the pharyngeal airway resulting in Class III malocclusions.[1] More notably, Edward Angle showed that Class II Division 1 malocclusion was correlated with obstruction of the pharyngeal airway and mouth breathing.[2] Additionally, lip incompetency, maxillary constriction, upper incisor procumbency, adenoid hypertrophy, open bite, and class II malocclusion were reported in patients with impaired respiratory function who were mouth breathers.[3]

While the pharyngeal space is primarily determined by the growth and size of neighboring soft tissues surrounding the dentofacial structures, a patent airway is logically necessary for the completion of normal arch development, dental alignment, dentofacial growth, and harmony of perioral and masticatory muscles.[3] Thus, the airway and the structures surrounding it are in a delicate interdependent balance. If one aspect is affected, the other will become disturbed, leading to consequences with clinical significance. For example, the airway space can be reduced by neighboring dentofacial anomalies, such as mandibular retrognathism, short mandibular body, and hyperdivergent mandibles.[2,3] The airway space can also be altered by obstructive processes of morphologic or pathologic nature because they affect the position of the hyoid and soft palate, which ultimately can reduce the airway.[2,3] Additionally, obstructive processes of the adjacent structures, such as polyps, tumors, nasal deformities, and adenoid hypertrophy, predispose patients to a deficient pharyngeal airway, which increases the likeliness of oral breathing.[2] On the other hand, patients with congenitally impaired respiratory function have developed dentofacial anomalies, such as crossbites, retrognathic mandibles, due to the early disruption in the balance between airway and dentofacial development.[3,4]

A deficient or impaired respiratory function can also predispose individuals to sleep-disordered breathing (SDB), which ranges from chronic or habitual snoring to obstructive sleep apnea (OSA).[3,4] Untreated OSA in adults has been associated with cardiovascular disease and hypertension.[5] Untreated sleep-disordered breathing in children and adolescents is associated with attention-deficit hyperactivity disorder (ADHD), snoring, daytime lethargy, and lower academic performance.[3,5] Thus, early diagnosis of SDB is imperative in order to promote normal facial development.[5]

Adenoid hypertrophy is the most common cause of mouth breathing and one of the most common causes of anatomic constrictions of the airway, especially in children and adolescents with SDB.[5] Adenoids are lymphatic tissues, which are found in the posterior pharyngeal airway. Any infection or inflammation of these lymphatic tissues can lead to a partial pharyngeal airway obstruction.[2] "Adenoid facies" is a term used to describe a possible aberrant craniofacial growth pattern that is commonly seen in mouthbreathers.[2] While several methods, including nasal endoscopy, rhinomanometry, 3-dimensional cone beam computed tomography (CBCT), and MRI, can be used to identify adenoid hypertrophy, the conventional 2-dimensional lateral cephalogram is still believed to be the most cost effective and reproducible method in determining adenotonsillar size.[6,7] Since a majority of the orthodontic patients consist of children and adolescents, orthodontists are likely to be the primary provider to screen young patients for this condition over otolaryngologists. Therefore, an orthodontist's responsibilities include not only improvement of esthetics and function, but also early recognition of pharyngeal airway impairments.

Silva et al.'s study used a total of 80 lateral cephalograms, 40 Class I and 40 Class II patients to evaluate this relationship. The two groups were matched by age to account for minor changes in nasopharynx because of growth. The study limited their Class II subjects to mandibular deficiency cases in an effort to better understand the factors related to changes in pharyngeal airway.[12] The study found that Class II malocclusion patients had reduced sagittal airway measurements compared to Class I individuals.[12] The oropharynx size, nasopharynx size, mandibular position, and mandibular length were also reduced in Class II patients.[12] Additionally, there was a statistically significant positive correlation between the oropharynx size and Xi-Pm, Co-Gn, and SNB measurements, which confirms the association between retrognathic mandible and reduced airway.[12]

Kim et al.'s study also used ANB angle and other cephalometric measurements to classify subjects into Class I (ANB 2° to 5°) and Class II (ANB>5°). This study used CBCT scans and 2D lateral cephalograms derived from CBCT scans to analyze 4 sub regions of the pharyngeal airway created by 5 cross-sectional planes. While the mean total airway volume in Class II patients was significantly reduced, the differences in volume measurements of 4 sub regions of airway were not statistically significant between the different malocclusions.[2] Anterior and posterior facial heights were positively correlated to total airway volume, which is inconsistent with many studies that have shown vertical growth patterns to be more prone to narrow airways.[2] However, the variables used to assess vertical growth patterns are different in this study from those in other studies that show the inverse relationship. Anteroposterior measurements, such as ANB angle and mandibular length, showed significant correlation to total airway volume, supporting the common understanding that a relationship exists between a retrognathic mandible and narrow airway.[2]

Claudino et al.'s study evaluated airway volumes using CBCT of skeletal Class I (ANB 1° to 3°), Class II (ANB >3°), and Class III (ANB<1°) patients based on ANB angle alone because the study claimed that ANB angle was the most used criteria in determination of anteroposterior relationship between the maxilla and mandible.[4] Once volume, minimal axial area, and total length of lower pharyngeal portion, velopharynx, oropharynx, and hypopharynx were obtained, the mean area of each segment was calculated. The Class II group had smaller minimum and mean areas in the lower pharyngeal portion, velopharynx, and oropharynx than did the Class III group. The study concluded that there is a negative correlation between ANB angle and airway volume in the lower pharyngeal portion, velopharynx (both sexes), and oropharynx (males), which is consistent with most studies.[4]

CHAPTER TWO

A RETROSPECTIVE CEPHALOMETRIC GROWTH STUDY OF SAGITTAL AIRWAY IN SKELETAL CLASS II PATIENTS

Abstract

Purpose: The study retrospectively determined the average sagittal pharyngeal airway widths in Class II males and females between 7 to 16 years of age and changes in sagittal airway with increasing age. Additionally, this study determined whether average airway differs between gender at each age and compared the average airway widths in relation to increasing age between Class I and II patients.

Materials and Methods: Longitudinal cephalograms were digitally traced for 38 untreated subjects (23 males, 15 females) from age 7 to 16 with skeletal and dental Class II patterns. These records were previously taken through growth studies conducted between 1930-70s. Six horizontal lines perpendicular to Orbitale Vertical were traced through the following landmarks: anterior nasal spine (1A-1B), A-point (2A-2B), upper incisor tip (3A-3B), B-point (4A-4B), pogonion (5A-5B), soft palate tip (6A-6B). The intersections of these planes with the anterior and posterior limits of the airway were measured.

Results:

> ***Class II:*** Males had more sagittal airway width, ranging from 2-8mm more than that of females at 1A-1B, 2A-2B, 4A-4B, 5A-5B, and 6A-6B (*P*=0.00-0.04). There was a significant increase in sagittal width from 7 to 16 years of age at 1A-1B for females (*P*=0.02) and 5A-5B for males (*P*=0.00).

Class I vs. II: While Class I females had more significant airway width at 3A-3B and 5A-5B than Class II females at age 11 and 12, respectively, the vice versa was true at 4A-4B at age 12. Class II males had more airway width at 1A-1B, 4A-4B, and 5A-5B of 1-7mm more than Class I males (P=0.00-0.05). No statistical difference was found in change in airway with increasing age between Class I and II patients.

Conclusions: Class II males had more airway width of 2-8mm more than that of Class II females at 1A-1B, 2A-2B, 4A-4B, 5A-5B, and 6A-6B (P=0.00-0.04). Class II males had more airway width at 1A-1B, 4A-4B, and 5A-5B of 1-7mm more than that of Class I males (P=0.00-0.05). Sagittal airway widths increased by a few millimeters in Class I and II patients with increasing age from 7 to 16.

Introduction

There are several dentofacial characteristics that are associated with impaired respiratory, airway obstruction, and subsequent mouth breathing, those being: lip incompetency, maxillary constriction, incisor proclination, adenoid hypertrophy, open bite, and class II malocclusion.[2,3] Since these findings are routinely encountered during a clinical orthodontic exam, orthodontists are well positioned to detect these signs and symptoms and diagnose breathing problems early. In doing so, patients might receive more timely care eliminating or slowing the progression of SDB. Untreated SDB in children and adolescents has been associated with ADHD, snoring, daytime lethargy, and lower academic performance.[3,5] Thus, early diagnosis of SDB is imperative in order to promote normal facial development.[5]

In addition, with the common use of lateral cephalograms in orthodontics, orthodontists can routinely use this tool to assess sagittal airway based on age and gender. In order to integrate airway measurements into a conventional cephalometric analysis, determining an average reference range for sagittal airway in adolescents will facilitate the recognition of deviations from normative values. This will aid in early diagnosis and treatment of constricted airways, which can help promote normal dentofacial development early on before more invasive and drastic measures must be taken in the future.[20]

Despite the vast amount of research in airway dimensions and their influence on dentofacial growth and development, many questions remain unanswered. Possible reasons include the multifactorial etiology of malocclusion and lack of longitudinal studies that can control for confounding variables caused by inter-subject variability.

More importantly, literature about airway dimensions in growing subjects is scarce. Little is known about the development of airway dimensions in children and whether age or gender has a significant influence on airway dimensions.

Since literature on normative sagittal dimensions for the physiologic airway is lacking,[11] Woo conducted a retrospective cephalometric growth study of sagittal airway changes in untreated Class I patients.[38] This longitudinal study evaluated sagittal airway changes in untreated Class II patients with gender and increasing age using the same database and compared sagittal airway changes between Class I and Class II patients.

Null Hypotheses

1. No difference in sagittal pharyngeal airway exists between Class II males and females in each respective age group from 7 to 16 years old, inclusive.
2. No change in sagittal pharyngeal airway exists with increasing age in Class II patients within each gender group from 7 to 16 years old, inclusive.
3. No difference in sagittal pharyngeal airway exists between Class I and Class II patients within each gender at each respective age group from 7 to 16 years old, inclusive.
4. No change in sagittal pharyngeal airway exists with increasing age between Class I and Class II patients within each gender group at each respective age group from 7 to 16 years old, inclusive.

Materials and Methods

Database Selection

The American Association of Orthodontists Foundation (AAOF) Craniofacial Growth Legacy Collection provides a unique database from several locations around the United States of America. The Case Western Bolton Brush Growth Study, University of Oklahoma Denver Growth Study, Oregon Growth Study, Michigan Growth Study, University of Toronto Burlington Growth Study, Forsyth Institute Sample, Iowa Facial Growth Study, and UOP Mathews Growth Study were used for this study. Past cross-sectional studies have examined the airway of different subjects in different age groups. However, the samples in each AAOF Growth Study consist of serial cephalometric radiographs taken for each individual either annually or bi-annually between the 1930s to 1970s.[24]

No studies have been conducted evaluating sagittal airway widths for a sample using serial lateral cephalograms taken annually or bi-annually during the period of 7-16 years of age. This database consisted of reliable, standardized data which allowed measurements of the sagittal airway from 7-16 years of age for each individual patient.

Cephalograms were taken no more than 6 months before or after their birthdays.[25,26] When more than one cephalogram was taken within 6 months of the patient's birthday, the one taken closest to the birthday was traced.

Biases inherent in the sample included a lack of standardization in head position and posture in the original collection of data. In addition, the subjects' detailed health histories were not available. Thus, the presence or absence of previous airway-related issues were unknown.

Patient Selection

The online AAOF Craniofacial Growth Legacy Collection for the Bolton-Brush, Denver, Michigan, Oregon, Burlington, Forsyth, Iowa, and Mathews Growth Study was utilized for skeletal and dental Class II patients with readable lateral cephalograms. The exclusion criteria were:

- Missing more than one cephalogram in the series between age 7 and 16, inclusive
- Missing cephalogram in the series at either age 7 or 16
- Not being Angle Class II relationship (mesiobuccal groove of the mandibular first molar is distal to the mesiobuccal cusp tip of the maxillary first molar)
- Not being skeletal Class II (ANB >6°, inclusive) at age 7
- Cephalogram with landmarks cut off at age 7 or 16
- Cephalograms with poor resolution
- Fixed appliances at any point along the longitudinal studies

All subjects were untreated Caucasians. The study included subjects with at most one cephalogram missing that met the exclusion criteria if that specific cephalogram was not taken at age 7 or 16.

Table 1 shows the number of males and females that met the established criteria and were included in the study. A total of 38 patients, consisting of 23 males and 15 females from 8 locations, were used in this study.

Table 1. Demographics of Subjects Derived from AAOF Longitudinal Growth Studies

Location	Males	Females	Total
Burlington	6	4	10
Bolton-Brush	6	6	12
Denver	3	1	4
Iowa	0	2	2
Mathews	0	1	1
Forsyth	3	0	3
Michigan	4	0	4
Oregon	1	1	2
Total	**23**	**15**	**38**

Image Acquisition and Data Collection

The cephalograms were downloaded from the AAOF Craniofacial Growth Legacy Collection website. Coordinate values of known distances, called fiducials, were used to ensure that scanned images were correctly scaled to the digital images. Fiducials are reference points embedded into digital images.[21] Quick Ceph Studio® (Version 3.9.1; Quick Ceph Systems, Inc., San Diego, Calif)[22] was used to digitally trace all landmarks and conduct measurements. Each image was scaled in Quick Ceph Studio® based on instructions given by the AAOF. The brightness, contrast, and gamma of each image were digitally manipulated to increase the clarity of the landmarks.

For each cephalogram, a vertical line perpendicular to Frankfort Horizontal (line from center of mechanical Porion to Orbitale) through Orbitale, called Orbitale Vertical, was drawn. The center point of the ear-rod was used as the mechanical Porion to eliminate error caused by different-sized ear-rods among the various growth studies and the inability to distinguish between right and left Porion.

Six horizontal lines perpendicular to this Orbitale Vertical were digitally traced and measured through each of the following landmarks to the most anterior and posterior limits of the airway (Table 2): ANS, A-pt, U1, B-pt, Pog, and SP. Figure 1 shows the intersection of these six planes with the anterior and posterior limits of the airway (Table 3). In addition, the Total Face Height (TFH) was measured for each cephalogram.

The most anterior incisor was traced when incisors were not aligned. Deciduous incisors were traced when permanent incisors were absent on the cephalograms. However, if the patient did not have erupted incisors, the tip of the developing incisor was traced.

Table 2. Cephalometric Landmarks

Landmarks for Orientation	Abbreviation	Definition
Mechanical Porion	Po	The center of ear rod
Orbitale	Or	The most inferior point on the orbital margin
Landmarks for Measurement	**Abbreviation**	**Definition**
ANS	ANS	The anterior limit of the anterior nasal spine
Point A	A-pt	The most concave point of the anterior maxilla
Maxillary Incisor Tip	U1	The incisal tip of the most prominent maxillary incisor
Point B	B-pt	The most concave point on the mandibular symphysis
Pogonion	Pog	The most anterior point of the mandibular symphysis
Soft Palate Tip	SP	The posterior and inferior limit of the soft palate

Table 3. Sagittal Airway Dimension Measurements Along Six Planes

Plane	Definition
1A-1B	Distance from most anterior to posterior limit of airway, along line perpendicular to Orbitale Vertical and through ANS
2A-2B	Distance from most anterior to posterior limit of airway, along line perpendicular to Orbitale Vertical and through A-pt
3A-3B	Distance from most anterior to posterior limit of airway, along line perpendicular to Orbitale Vertical and through U1
4A-4B	Distance from most anterior to posterior limit of airway, along line perpendicular to Orbitale Vertical and through B-pt
5A-5B	Distance from most anterior to posterior limit of airway, along line perpendicular to Orbitale Vertical and through Pog
6A-6B	Distance from SP to posterior limit of airway, along line perpendicular to Orbitale Vertical and SP

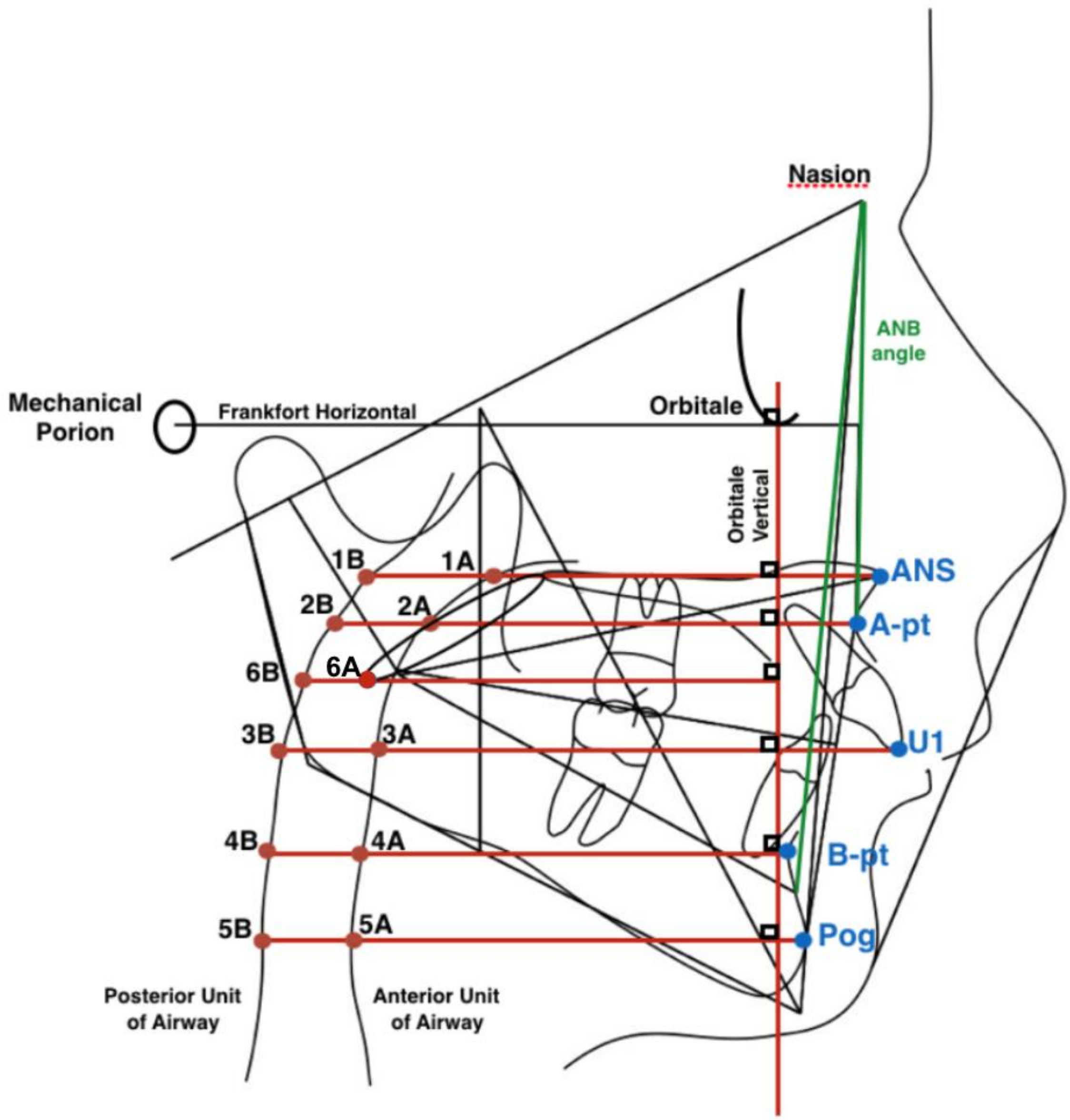


Figure 1. Landmarks and Sagittal Airway Dimensions Along Six Planes

Figure 1 illustrates the landmarks and linear measurements that were measured. Figure 2 shows an example of a digital tracing on a cephalogram using Quick Ceph Studio®. Appendix A shows the landmarks that were digitally traced for each cephalogram and Appendix B shows the numerical values of all measurements.

In summary, the following values were recorded: location, patient identification number, gender, age, TFH, ANB, 1A-1B, 2A-2B, 3A-3B, 4A-4B, 5A-5B, and 6A-6B.

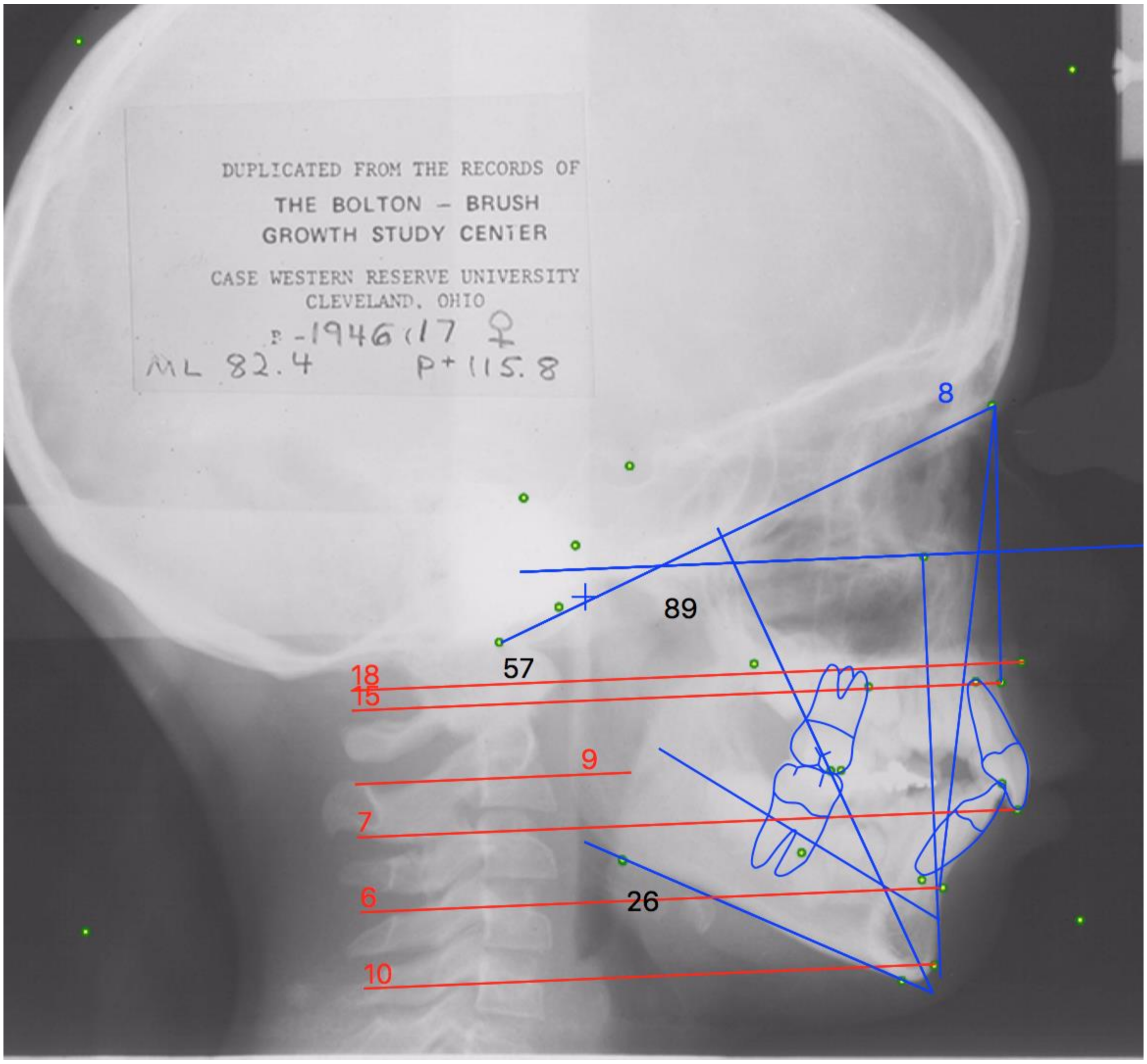


Figure 2. Illustration of a digital tracing on a cephalogram using Quick Ceph Studio®

Statistical Analysis

SPSS™ 23.0 (SPSS Inc., Chicago, IL, USA) and Microsoft® Excel were used for statistical analyses.

A pilot study of two males and two females was conducted, and a power analysis showed that a sample size of 32 patients is required to find a difference in sagittal airway between males and females with increasing age for 80% power. Thus, our sample size of 38 patients demonstrated more than adequate power for our statistical purposes.

To determine intra-observer reliability, 15% of the cephalograms were randomly selected and digitally traced. After two weeks, the same cephalograms were retraced and measured by the same investigator. The Intraclass Correlation Coefficient (ICC) was used to determine whether there is intra-observer error associated with the digital tracings and measurements. The average ICC was 98.0%, lowest ICC was 92.3%, and greatest ICC was 99.4%. The ICC demonstrated excellent agreement and reliability in all airway measurements (Table 4).

Table 4. Intraclass Correlation Coefficient

Average ICC	0.980
Min ICC	0.923
Max ICC	0.994

Analysis of co-variance (ANCOVA) was used to determine any independent effect from multiple co-variates, such as age, gender, and location of study, on the airway measurements. ANCOVA was the main test used in this study to analyze for multiple effects on airway measurements.

The effect of gender on sagittal airway for each age group and the effect of increasing age on sagittal airway within each gender were determined. The ANCOVA test evaluated the difference in mean sagittal airway between males and females within each age category and between each consecutive age group. The ANCOVA test also evaluated if there was a significant difference in sagittal airway between Class I and Class II patients within each gender and if there is a significant change in sagittal airway with increasing age in Class I and Class II. *P*-values less than 0.05 were considered statistically significant.

Results

The Sharpiro-Wilk and Kolmogorov-Smirnov test indicated a non-normal distribution in several co-variates (i.e. age, gender). Thus, all raw data was ranked to conserve power. Additionally, a post-hoc Tamhane test indicated that location of where the cephalograms were taken had statistically significant independent effect on the airway measurements (Table 5). As a result, location was controlled for all analyses.

The Mann-Whitney U Test was used to determine the influence of gender on a specific airway measurement at a specific age. Table 6 indicates that Class II males had more sagittal airway width than Class II females at all ages, except at age 7 for 3A-3B and age 12 for 4A-4B. Class II males had statistically greater 1A-1B measurement at age 7 ($P = 0.020$) and 13 ($P = 0.017$), 2A-2B measurement at age 7 ($P = 0.070$), 4A-4B measurement at age 13 ($P = 0.021$), 14 ($P = 0.044$), and 16 ($P = 0.016$), and 5A-5B measurement at age 8 ($P = 0.006$), 13 ($P = 0.030$), 14 ($P = 0.037$), 15 ($P = 0.007$), and 16 ($P = 0.000$) than Class II females of the respective ages. Class II males had statistically greater 6A-6B measurement at age 7 ($P = 0.042$), 8 ($P = 0.036$), 9 ($P = 0.008$), 11 ($P = 0.009$), 12 ($P = 0.019$), 13 ($P = 0.010$), 14 ($P = 0.002$), 15 ($P = 0.017$), and 16 ($P = 0.000$).

The Kruskal-Wallis Test was used to measure the change in airway dimension with increasing age in Class II males and females separately. Change in airway was calculated as the difference between the younger age and older age. There was a statistical significant increase in 1A-1B in Class II females from 7 to 16 years of age (*P* = 0.023) of 5.436mm (Table 7). There was a statistical significant increase in 5A-5B in Class II males from 7 to 16 years of age (*P* = 0.003) of 4.962mm (Table 8). If the *P*-value is greater than 0.05 for the Kruskal-Wallis Test for each airway measurement, “NS” was labeled on the chart to indicate that the *P*-values were non-significant.

The ANCOVA in Table 9 indicates the mean difference in sagittal airway dimension between Class I and Class II females. Class I females at age 11 and 8 had a statistically greater 3A-3B (*P* = 0.049) and 5A-5B (*P* = 0.018) measurement, respectively, than Class II females at that age. On the contrary, Class II females at age 12 had a statistically greater 4A-4B (*P* = 0.041) measurement than Class I females at that age.

The ANCOVA in Table 10 illustrates the mean difference in sagittal airway dimension between Class I and Class II males. Class II males had a statistically greater 1A-1B measurement at age 9 (*P* = 0.008), 10 (*P* = 0.025), 13 (*P* = 0.008), and 14 (*P* = 0.046) than Class I males at the respective ages. Class II males had a statistically greater 4A-4B measurement at age 7 (*P* = 0.047), 10 (*P* = 0.012), 11 (*P* = 0.006), 12 (*P* = 0.016), 13 (*P* = 0.003), 14 (*P* = 0.003), 15 (*P* = 0.004), and 16 (*P* = 0.000) than Class I males at the respective ages. Class II males had a statistically greater 5A-5B measurement at age 13 (*P* = 0.029) and 16 (*P* = 0.005) than Class I males at the respective ages.

To study the change in sagittal pharyngeal airway with increasing age between Class I and Class II patients within each gender, the differences in airway was studied using a generalized linear model with link function. There was no statistical significant difference in change in airway with increasing age between Class I and Class II patients.

The estimated marginal mean (Figure 3-8) with 95% confidence interval and standard error for each of the six sagittal airway dimensions in Class II patients were calculated after controlling for location (Appendix C).

The total change in TFH between age 7 and 16 is shown in Appendix D. The greatest decrease in TFH between age 7 and 16 was 10.0°, while the greatest increase was 2.8°.

Table 5A. Post-Hoc Tamhane Test showing differences in 1A-1B and 2A-2B measurements based on location

Plane	Location	Location	Sig.	Plane	Location	Location	Sig.
1A-1B	Bolton	Denver	1.000	2A-2B	Bolton	Denver	1.000
		Michigan	0.000*			Michigan	0.996
		Oregon	1.000			Oregon	1.000
		Burlington	1.000			Burlington	0.549
		Forsyth	0.402			Forsyth	0.000*
		Iowa	0.520			Iowa	0.678
		Mathews	0.999			Mathews	0.894
	Denver	Michigan	0.000*		Denver	Michigan	0.999
		Oregon	1.000			Oregon	1.000
		Burlington	1.000			Burlington	0.863
		Forsyth	0.398			Forsyth	0.002*
		Iowa	0.965			Iowa	0.800
		Mathews	0.997			Mathews	0.927
	Michigan	Oregon	0.013*		Michigan	Oregon	1.000
		Burlington	0.000*			Burlington	0.387
		Forsyth	0.997			Forsyth	0.009*
		Iowa	0.000*			Iowa	0.460
		Mathews	0.321			Mathews	0.992
	Oregon	Burlington	1.000		Oregon	Burlington	0.835
		Forsyth	0.741			Forsyth	0.017*
		Iowa	0.887			Iowa	0.744
		Mathews	1.000			Mathews	0.988
	Burlington	Forsyth	0.393		Burlington	Forsyth	0.000*
		Iowa	0.885			Iowa	0.999
		Mathews	0.998			Mathews	0.396
	Forsyth	Iowa	0.113		Forsyth	Iowa	0.000*
		Mathews	0.950			Mathews	0.409
	Iowa	Mathews	0.852		Iowa	Mathews	0.334

Table 5B. Post-Hoc Tamhane Test showing differences in 3A-3B and 4A-4B measurements based on location

Plane	Location	Location	Sig.	Plane	Location	Location	Sig.
3A-3B	Bolton	Denver	0.000*	4A-4B	Bolton	Denver	0.000*
		Michigan	0.062			Michigan	0.003*
		Oregon	0.777			Oregon	11.000
		Burlington	0.031			Burlington	0.000*
		Forsyth	0.001*			Forsyth	0.002*
		Iowa	0.999			Iowa	1.000
		Mathews	0.186			Mathews	0.728
	Denver	Michigan	0.489		Denver	Michigan	0.668
		Oregon	0.342			Oregon	0.797
		Burlington	0.067			Burlington	0.201
		Forsyth	0.985			Forsyth	0.998
		Iowa	0.001*			Iowa	0.001*
		Mathews	1.000			Mathews	0.817
	Michigan	Oregon	0.999		Michigan	Oregon	1.000
		Burlington	1.000			Burlington	1.000
		Forsyth	0.376			Forsyth	0.684
		Iowa	0.228			Iowa	0.215
		Mathews	0.994			Mathews	1.000
	Oregon	Burlington	1.000		Oregon	Burlington	1.000
		Forsyth	0.245			Forsyth	0.727
		Iowa	0.751			Iowa	0.458
		Mathews	0.953			Mathews	1.000
	Burlington	Forsyth	0.158		Burlington	Forsyth	0.456
		Iowa	0.301			Iowa	0.230
		Mathews	0.950			Mathews	1.000
	Forsyth	Iowa	0.004*		Forsyth	Iowa	0.018*
		Mathews	0.959			Mathews	0.708
	Iowa	Mathews	0.204		Iowa	Mathews	0.871

Table 5C. Post-Hoc Tamhane Test showing differences in 5A-5B and 6A-6B measurements based on location

Plane	Location	Location	Sig.	Plane	Location	Location	Sig.
5A-5B	Bolton	Denver	0.000*	6A-6B	Bolton	Denver	0.227
		Michigan	0.000*			Michigan	0.983
		Oregon	0.123			Oregon	0.898
		Burlington	0.000*			Burlington	0.947
		Forsyth	0.005*			Forsyth	0.002*
		Iowa	0.787			Iowa	0.233
		Mathews	1.000			Mathews	1.000
	Denver	Michigan	1.000		Denver	Michigan	0.939
		Oregon	0.988			Oregon	1.000
		Burlington	0.796			Burlington	0.023*
		Forsyth	0.983			Forsyth	0.278
		Iowa	0.619			Iowa	0.003*
		Mathews	0.063			Mathews	0.977
	Michigan	Oregon	0.999		Michigan	Oregon	1.000
		Burlington	0.958			Burlington	0.646
		Forsyth	0.945			Forsyth	0.038*
		Iowa	0.806			Iowa	0.095
		Mathews	0.123			Mathews	1.000
	Oregon	Burlington	1.000		Oregon	Burlington	0.511
		Forsyth	0.821			Forsyth	0.209
		Iowa	0.994			Iowa	0.070
		Mathews	0.481			Mathews	0.999
	Burlington	Forsyth	0.592		Burlington	Forsyth	0.000*
		Iowa	0.992			Iowa	0.695
		Mathews	0.356			Mathews	0.995
	Forsyth	Iowa	0.398		Forsyth	Iowa	0.000*
		Mathews	0.045*			Mathews	0.130
	Iowa	Mathews	0.898		Iowa	Mathews	0.661

Table 6. ANCOVA showing difference in mean airway in each age group between Class II males and females

		1A-1B		2A-2B		3A-3B		4A-4B		5A-5B		6A-6B	
Age	**Gender**	**Mean**	**Sig.**	**Mean**	**Sig.**	**Mean**	**Sig.**	**Mean**	**Sig.**	**Mean**	**Sig.**	**Mean**	**Sig.**
7	F	11.224	0.020*	10.643	0.070*	10.591	0.149	8.524	0.168	9.298	0.102	8.244	0.042*
	M	19.585		14.406		12.539		10.292		12.746		12.649	
8	F	13.827	0.140	11.847	0.290	12.625	0.320	8.230	0.058	9.934	0.006*	8.647	0.036*
	M	17.590		14.316		11.742		9.421		11.875		10.534	
9	F	15.160	0.088	13.683	0.545	10.447	0.172	9.227	0.151	12.151	0.781	9.847	0.008*
	M	19.287		14.868		12.028		11.072		12.975		11.591	
10	F	15.717	0.539	14.101	0.987	11.205	0.888	9.290	0.249	12.311	0.459	9.573	0.352
	M	18.277		14.915		12.467		12.091		14.180		11.808	
11	F	16.104	0.404	12.669	0.369	10.164	0.336	9.292	0.158	10.376	0.053	9.066	0.009*
	M	18.331		14.548		12.459		12.083		15.232		12.523	
12	F	14.660	0.179	12.713	0.147	11.263	0.607	12.100	0.410	13.775	0.973	9.618	0.019*
	M	20.050		13.754		12.264		11.971		14.294		11.137	
13	F	15.338	0.017*	14.113	0.354	10.413	0.271	8.518	0.021*	12.539	0.030*	8.468	0.010*
	M	21.975		14.775		13.106		12.650		16.069		14.228	
14	F	16.395	0.088	13.987	0.441	11.568	0.088	9.571	0.044*	11.976	0.037*	9.680	0.002*
	M	20.655		15.946		14.328		14.497		16.811		13.747	
15	F	18.288	0.794	15.392	0.744	12.992	0.292	9.920	0.051	12.804	0.007*	10.088	0.017*
	M	17.243		15.751		14.176		13.789		16.138		14.125	
16	F	16.660	0.116	13.964	0.178	12.418	0.124	10.228	0.016*	12.789	0.000*	9.816	0.000*
	M	23.270		16.529		15.541		13.978		17.708		14.176	

Table 7. ANCOVA showing changes in airway with increasing age in Class II females. Change is calculated as the difference in mean between the younger age and the older age.

Age	1A-1B			2A-2B			3A-3B			4A-4B			5A-5B			6A-6B		
	Mean	Change	Sig	Mean	Change	Sig	Mean	Change	Sig	Mean	Change	Sig	Mean	Change	Sig	Mean	Change	Sig
7	11.224	-2.603	1.000	10.643	-1.204	1.000	10.591	-2.034	NS	8.524	0.294	NS	9.298	-0.636	1.000	8.244	-0.403	NS
8	13.827	-1.333	1.000	11.847	-1.836	1.000	12.625	2.178	NS	8.230	-0.997	NS	9.934	-2.217	0.852	8.647	-1.200	NS
9	15.160	-0.557	1.000	13.683	-0.418	1.000	10.447	-0.758	NS	9.227	-0.063	NS	12.151	-0.160	1.000	9.847	0.274	NS
10	15.717	-0.387	1.000	14.101	1.432	1.000	11.205	1.041	NS	9.290	-0.002	NS	12.311	1.935	1.000	9.573	0.507	NS
11	16.104	1.444	1.000	12.669	-0.044	1.000	10.164	-1.099	NS	9.292	-2.808	NS	10.376	-3.399	1.000	9.066	-0.552	NS
12	14.660	-0.678	1.000	12.713	-1.400	1.000	11.263	0.850	NS	12.100	3.582	NS	13.775	1.236	1.000	9.618	1.150	NS
13	15.338	-1.057	1.000	14.113	0.135	1.000	10.413	-1.155	NS	8.518	-1.053	NS	12.539	0.563	1.000	8.468	-1.212	NS
14	16.395	-1.893	1.000	13.978	-1.414	1.000	11.568	-1.424	NS	9.571	-0.349	NS	11.976	-0.828	1.000	9.680	-0.408	NS
15	18.288	1.628	1.000	15.392	1.428	1.000	12.992	0.574	NS	9.920	-0.308	NS	12.804	0.015	1.000	10.088	0.470	NS
16	16.660			13.964			12.418			10.228			12.789			9.816		
7 to 16		-5.436	0.023*		-3.321	0.102		-1.827	NS		-1.704	NS		-3.491	0.676		-1.572	NS

Table 8. ANCOVA showing changes in airway with increasing age in Class II males. Change is calculated as the difference in mean between the younger age and the older age.

Age	1A-1B			2A-2B			3A-3B			4A-4B			5A-5B			6A-6B		
	Mean	Change	Sig	Mean	Change	Sig	Mean	Change	Sig	Mean	Change	Sig	Mean	Change	Sig	Mean	Change	Sig
7	19.585	1.995	NS	14.406	0.090	NS	12.539	0.797	NS	10.292	0.871	NS	12.746	0.871	1.000	12.649	2.115	1.000
8	17.590	-1.697	NS	14.316	-0.552	NS	11.742	-0.286	NS	9.421	-1.651	NS	11.875	-1.100	1.000	10.534	-1.057	1.000
9	19.287	1.010	NS	14.868	-0.047	NS	12.028	-0.439	NS	11.072	-1.019	NS	12.975	-1.205	1.000	11.591	-0.217	1.000
10	18.277	-0.054	NS	14.915	0.367	NS	12.467	0.008	NS	12.091	0.008	NS	14.180	-1.052	1.000	11.808	-0.715	1.000
11	18.331	-1.719	NS	14.548	0.794	NS	12.459	0.195	NS	12.083	0.112	NS	15.323	0.938	1.000	12.523	1.386	1.000
12	20.050	-1.925	NS	13.754	-1.021	NS	12.264	-0.842	NS	11.971	-0.694	NS	14.294	-1.775	1.000	11.137	-3.091	1.000
13	21.975	1.310	NS	14.775	-1.171	NS	13.106	-1.222	NS	12.665	-1.832	NS	16.069	-0.742	1.000	14.228	0.481	1.000
14	20.665	3.422	NS	15.946	0.195	NS	14.328	0.152	NS	14.497	0.708	NS	16.811	0.673	1.000	13.747	-0.378	1.000
15	17.243	-6.027	NS	15.751	-0.778	NS	14.176	-1.365	NS	13.789	-0.189	NS	16.138	-1.570	1.000	14.125	-0.051	1.000
16	23.270			16.529			15.541			13.978			17.708			14.176		
7 to 16		-3.685	NS		-2.123	NS		-3.002	NS		-3.686	NS		-4.962	0.003*		-1.527	0.891

Table 9. ANCOVA showing mean airway difference between skeletal Class I and Class II females patients

		1A-1B		2A-2B		3A-3B		4A-4B		5A-5B	
Age	Skeletal	Mean	Sig.	Mean	Sig.	Mean	Sig.	Mean	Sig.	Mean	Sig.
7	I	13.900	0.066	12.100	0.069	11.300	0.219	7.700	0.539	11.300	0.212
	II	11.224		10.643		10.591		8.524		9.298	
8	I	13.200	0.481	11.900	0.632	11.300	0.678	7.600	0.606	11.300	0.018*
	II	13.827		11.847		12.625		8.230		9.934	
9	I	14.700	0.956	12.700	0.748	11.200	0.101	8.300	0.460	11.700	0.928
	II	15.160		13.683		10.447		9.227		12.151	
10	I	15.400	0.778	13.000	0.323	12.100	0.077	7.400	0.109	11.800	0.620
	II	15.717		14.101		11.205		9.290		12.311	
11	I	15.100	0.903	12.500	0.823	11.600	0.049*	7.800	0.381	12.400	0.388
	II	16.104		12.669		10.164		9.292		10.376	
12	I	14.600	0.690	12.400	0.826	11.000	0.564	7.200	0.041*	12.200	0.379
	II	14.660		12.713		11.263		12.100		13.775	
13	I	15.800	0.336	13.100	0.781	11.200	0.740	7.800	0.240	12.700	0.910
	II	15.338		14.113		10.413		8.518		12.539	
14	I	15.600	0.708	13.200	0.446	11.700	0.475	7.900	0.266	12.600	0.970
	II	16.395		13.978		11.568		9.571		11.976	
15	I	15.600	0.084	12.900	0.156	10.800	0.913	7.900	0.870	12.900	0.361
	II	18.288		15.392		12.992		9.920		12.804	
16	I	16.000	0.550	13.200	0.281	11.800	0.695	8.100	0.163	13.200	0.455
	II	16.660		13.964		12.418		10.228		12.789	

Table 10. ANCOVA showing mean airway difference between skeletal Class I and Class II male patients

		1A-1B		2A-2B		3A-3B		4A-4B		5A-5B	
Age	Skeletal	Mean	Sig.	Mean	Sig.	Mean	Sig.	Mean	Sig.	Mean	Sig.
7	I	12.500	0.077	10.800	0.337	12.900	0.143	7.800	0.047*	11.200	0.466
	II	19.585		14.406		12.539		10.292		12.746	
8	I	13.200	0.072	11.600	0.156	12.800	0.254	7.800	0.173	12.100	0.647
	II	17.590		14.316		11.742		9.421		11.875	
9	I	13.000	0.008*	11.800	0.198	12.100	0.449	8.400	0.370	12.300	0.852
	II	19.287		14.868		12.028		11.072		12.975	
10	I	13.800	0.025*	12.400	0.165	12.100	0.570	8.200	0.012*	12.200	0.393
	II	18.277		14.915		12.467		12.091		14.180	
11	I	14.600	0.181	12.900	0.571	12.400	0.442	8.000	0.006*	12.600	0.162
	II	18.331		14.548		12.459		12.083		15.323	
12	I	14.800	0.063	13.200	0.751	12.200	0.725	7.800	0.016*	12.300	0.149
	II	20.050		13.754		12.264		11.971		14.294	
13	I	15.100	0.008*	13.600	0.201	13.800	0.481	8.700	0.003*	12.900	0.029*
	II	21.975		14.775		13.106		12.665		16.069	
14	I	14.700	0.046*	13.100	0.250	13.000	0.810	8.600	0.003*	13.600	0.064
	II	20.665		15.946		14.328		14.497		16.811	
15	I	16.100	0.773	14.400	0.836	13.800	0.515	8.900	0.004*	14.100	0.116
	II	17.243		15.751		14.176		13.789		16.138	
16	I	15.900	0.067	14.000	0.402	14.000	0.480	9.100	0.000*	14.200	0.005*
	II	23.270		16.529		15.541		13.978		17.708	

Table 11. ANCOVA showing changes in airway with increasing age between Class I and Class II female patients

		1A-1B		2A-2B		3A-3B		4A-4B		5A-5B	
Age	Skeletal	Change	Sig.	Mean	Sig.	Mean	Sig.	Mean	Sig.	Mean	Sig.
7	I	0.700	1.000	0.200	1.000	0.000	1.000	0.100	1.000	0.000	1.000
	II	-2.603		-1.204		-2.034		0.294		-0.636	
8	I	-1.500	1.000	-0.800	1.000	0.100	1.000	-0.700	1.000	-0.400	1.000
	II	-1.333		-1.836		2.178		-0.997		-2.217	
9	I	-0.700	1.000	0.300	1.000	-0.900	1.000	0.900	1.000	-0.100	1.000
	II	-0.557		-0.418		-0.758		-0.063		-0.160	
10	I	0.300	1.000	0.500	1.000	0.500	1.000	-0.400	1.000	-0.600	1.000
	II	-0.387		1.432		1.041		-0.002		1.935	
11	I	0.500	1.000	0.100	1.000	0.600	1.000	0.600	1.000	0.200	1.000
	II	1.444		-0.044		-1.099		-2.808		-3.399	
12	I	-1.200	1.000	-0.700	1.000	-0.200	1.000	-0.600	1.000	-0.500	1.000
	II	-0.678		-1.400		0.850		3.582		1.236	
13	I	0.200	1.000	-0.100	1.000	-0.500	1.000	-0.100	1.000	0.100	1.000
	II	-1.057		0.135		-1.155		-1.053		0.563	
14	I	0.000	1.000	0.300	1.000	0.900	1.000	0.000	1.000	-0.300	1.000
	II	-1.893		-1.414		-1.424		-0.349		-0.828	
15	I	-0.400	1.000	-0.300	1.000	-1.000	1.000	-0.200	1.000	-0.300	1.000
	II	1.628		1.428		0.574		-0.308		0.015	
7 to 16	I	-2.100	1.000	-1.100	1.000	-0.500	1.000	-0.400	1.000	-1.900	1.000
	II	-5.436		-3.321		-1.827		-1.704		-3.491	

Table 12. ANCOVA showing changes in airway with increasing age between Class I and Class II male patients

		1A-1B		2A-2B		3A-3B		4A-4B		5A-5B	
Age	Skeletal	Change	Sig.	Mean	Sig.	Mean	Sig.	Mean	Sig.	Mean	Sig.
7	I	-0.700	1.000	-0.800	1.000	0.100	1.000	0.000	1.000	-0.900	1.000
	II	1.995		0.090		0.797		0.871		0.871	
8	I	0.200	1.000	-0.200	1.000	0.700	1.000	-0.600	1.000	-0.200	1.000
	II	-1.697		-0.552		-0.286		-1.651		-1.100	
9	I	-0.800	1.000	-0.600	1.000	0.000	1.000	0.200	1.000	0.100	1.000
	II	1.010		-0.047		-0.439		-1.019		-1.205	
10	I	-0.800	1.000	-0.500	1.000	-0.300	1.000	0.200	1.000	-0.400	1.000
	II	-0.054		0.367		0.008		0.008		-1.052	
11	I	-0.200	1.000	-0.300	1.000	0.200	1.000	0.200	1.000	0.300	1.000
	II	-1.719		0.794		0.195		0.112		0.938	
12	I	-0.300	1.000	-0.400	1.000	-1.600	1.000	-0.900	1.000	-0.600	1.000
	II	-1.925		-1.021		-0.842		-0.694		1.775	
13	I	0.400	1.000	0.500	1.000	0.800	1.000	1.000	1.000	-0.700	1.000
	II	1.310		-1.171		-1.222		-1.832		-0.742	
14	I	-1.400	1.000	-1.300	1.000	-0.800	1.000	-0.300	1.000	-0.500	1.000
	II	3.422		0.195		0.152		0.708		0.673	
15	I	0.200	1.000	0.400	1.000	-0.200	1.000	-0.200	1.000	-0.100	1.000
	II	-6.027		-0.778		-1.365		-0.189		-1.570	
7 to 16	I	-3.400	1.000	-3.200	1.000	-1.100	1.000	-1.300	1.000	-3.000	1.000
	II	-3.650		-2.123		-3.002		-3.686		-4.962	

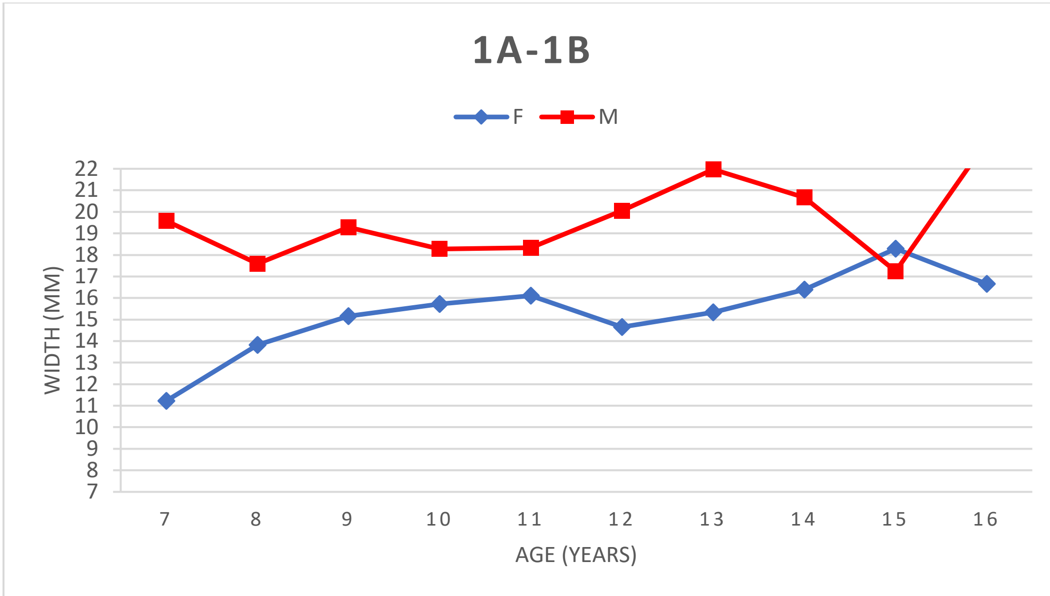


Figure 3. Estimated Marginal Means of Sagittal Airway Dimension on Plane 1

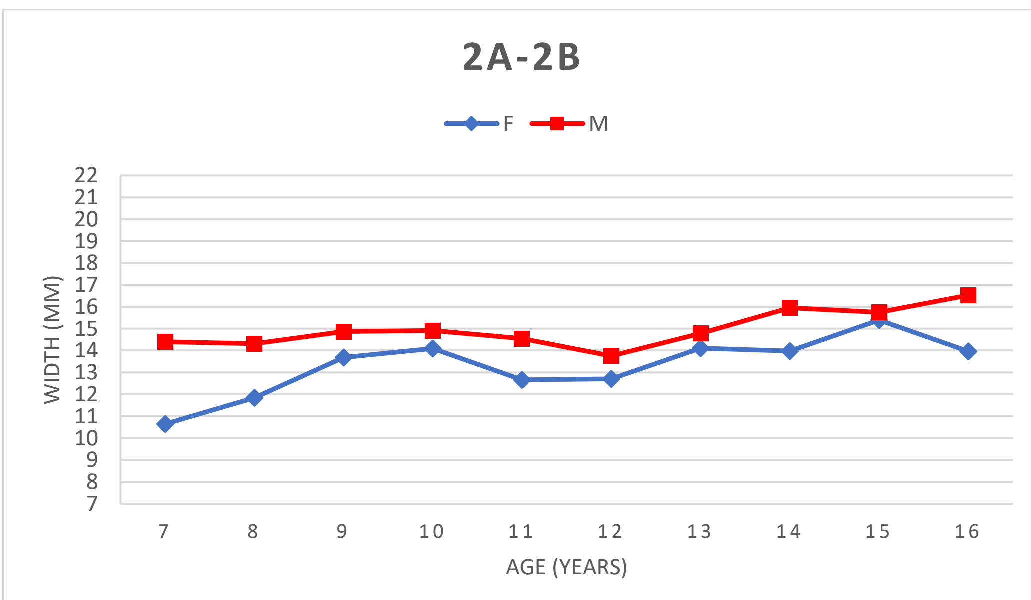


Figure 4. Estimated Marginal Means of Sagittal Airway Dimension on Plane 2

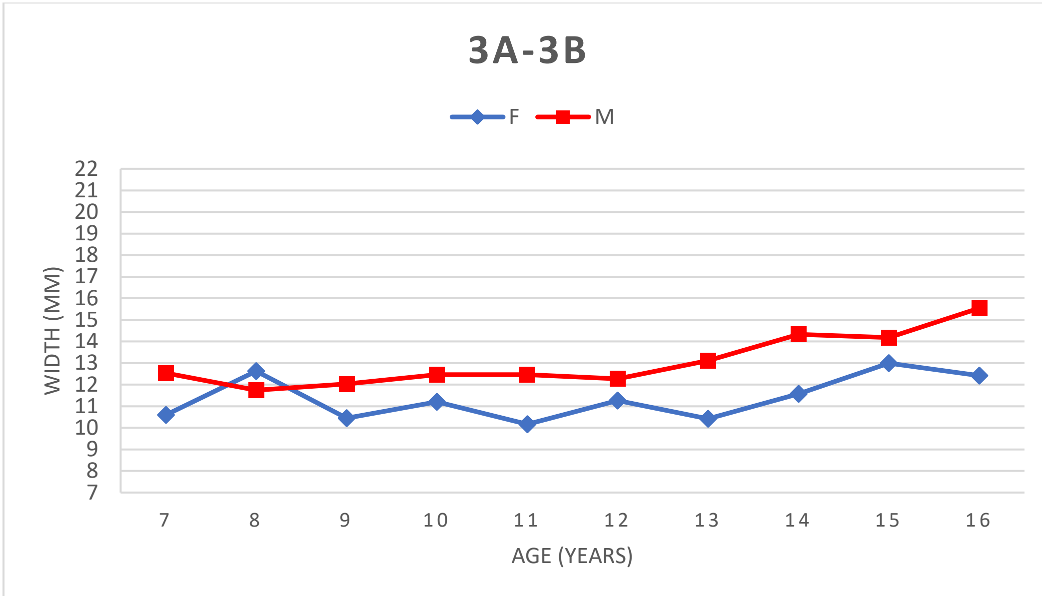


Figure 5. Estimated Marginal Means of Sagittal Airway Dimension on Plane 3

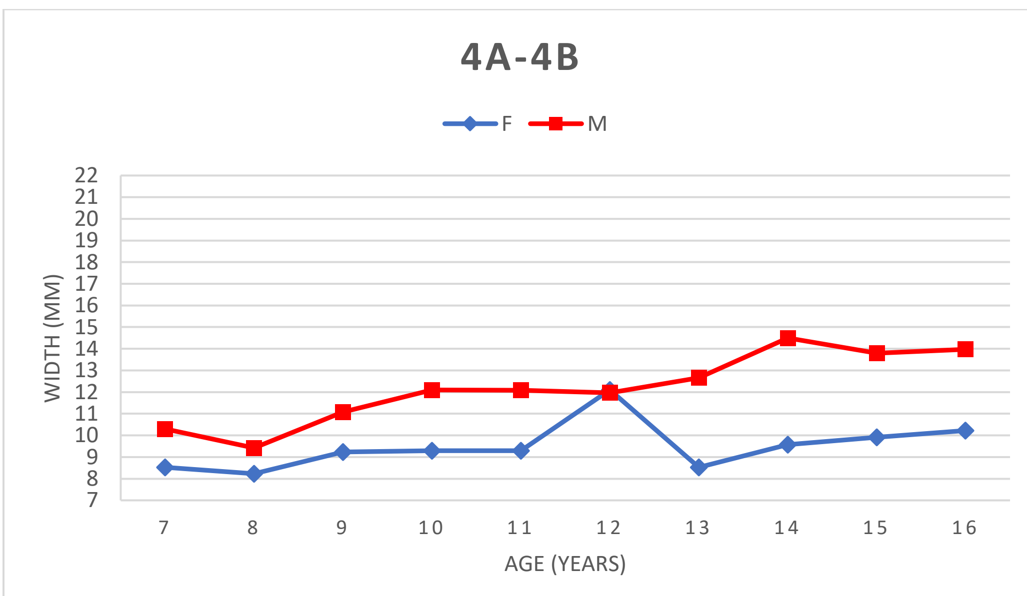


Figure 6. Estimated Marginal Means of Sagittal Airway Dimension on Plane 4

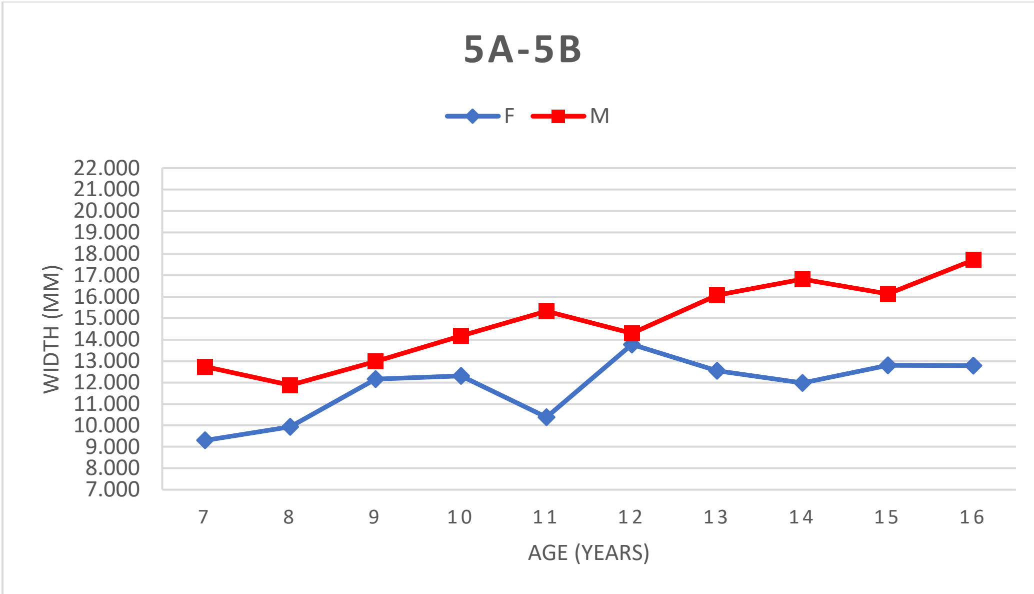


Figure 7. Estimated Marginal Means of Sagittal Airway Dimension on Plane 5

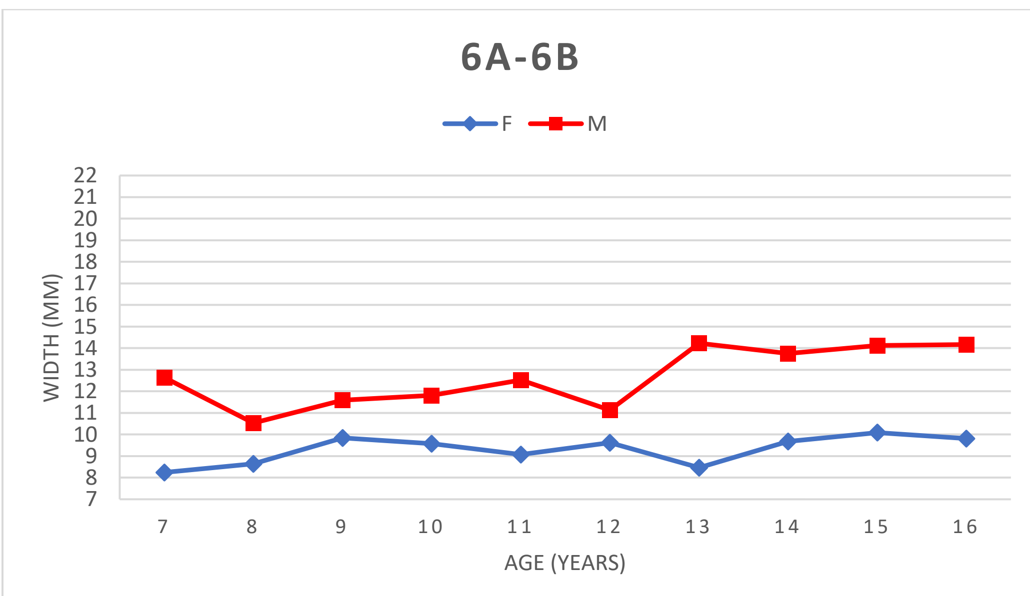


Figure 8. Estimated Marginal Means of Sagittal Airway Dimension on Plane 6

Discussion

The first three null hypotheses were rejected. There was a statistical significant difference in sagittal pharyngeal airway between Class II males and females. There was a statistical significant change in sagittal pharyngeal airway with increasing age in Class II patients within each gender group from age 7 to 16 at 1A-1B for females and 5A-5B for males. There was a statistical significant difference in sagittal pharyngeal airway between Class I and Class II patients within each gender. The last null hypothesis was unable to be rejected. There was no statistical significant change in sagittal pharyngeal airway with increasing age between Class I and Class II patients within each gender group from age 7 to 16.

Effect of Location on Sagittal Airway Dimension

Location was shown to have a statistically significant effect on airway measurements. Each growth study used in this study differed in time of data collection. Thus, environmental effects may have been accountable for the effect of location on airway measurements (Table 5).[5,27] The Bolton-Brush study was conducted between 1930-1950, Denver study between 1927-1967, the Michigan study between 1953-1970s, Oregon study between 1950-1970s, the Burlington study between 1952-1970s, Iowa study between 1946-1960, and Mathews study between 1967-1979. Environmental factors, such as air pollution and allergens, can change with time and have been shown in studies to affect pharyngeal airway dimensions.[28,29] Additionally, there was a lack of standardization in the radiographic technique for each subject among all eight locations.

Effect of Gender on Sagittal Airway Dimension

Unlike Woo's study which did not show sagittal airway dimensions to be statistically different between Class I males and females, this study showed Class II males to have statistically greater 1A-1B measurement at age 7 and 13, 2A-2B measurement at age 7, 4A-4B measurement at age 13, 14, and 16, 5A-5B measurement at age 8, 13, 14, 15, and 16, 6A-6B measurement at age 7, 8, 9, 11, 12, 13, 14, 15, and 16 than Class II females of the respective ages. This finding is consistent with several studies that found longer airway dimensions in males with increasing age and speculated that the soft tissue can become more collapsible with age, which would explain the higher rate of OSA in males.[30,31,32] Another study found a similar pattern of increased distance between the tip of the soft palate and posterior pharyngeal wall in males due to a more abrupt angle between the hard and soft palate, which essentially increases the distance between the uvula and posterior pharyngeal wall.[31] Another study by Daniel et al. also found males to have significantly greater average airway dimensions compared to women for all structures.[32]

Effect of Age on Sagittal Airway Dimension

Overall, sagittal airway dimensions had a relatively small increase with increasing age in both Class I and Class II patients between 7 and 16 years of age. However, the general trend was an increasing airway width with increasing age. This is most likely due to the shrinking of lymphoid tissues and forward drift of the palate with the maxilla's downward and forward growth.[5,26,33] The position of the tongue, absence of palatine tonsils, forward position of the hyoid bone, and forward position of the mandible also contribute to the increase in sagittal measurements of the inferior airway with increasing age.[34]

Most of the pharyngeal growth in Class I and II patients occurs incrementally by a few millimeters over the course of 7 through 16 years of age. In Class II patients, most growth occurred between age 7 to 16 by 5.45mm in females at 1A-1B and by 4.96mm in males at 5A-5B. Although the pharyngeal airway undergoes progressive changes during childhood, this study showed that the airway generally did not increase significantly for patients during development.

A study by Arens et al. suggested that the soft tissues, including tonsils and adenoid, surrounding the pharyngeal airway grow proportionally to the skeletal structures as the lower face grows linearly along the sagittal and axial planes from age 1 to 11.[35] This study used MRI to study the soft tissue surrounding the airway in normal children during development and hypothesized that changes in the anatomy of the tissues surrounding the airway during development serve to maintain airway patency by either regulating tissue growth rates to offset overgrowth of tissues or maintaining a proportional growth of all tissues.[35] This explains why despite the accelerated growth of adenoids during the childhood years, they snore less frequently and have less OSAs compared to adults, even though children have a smaller airway in comparison to adults.[35,36,37] The maintenance of proportional growth skeletally and in soft tissues ensures airway patency throughout childhood and contributes to airway stability in normal children.[35]

Another study stated that "considering how abundant craniofacial growth and development is between 6 and 17 years of age, it is contrary to expectation that no radical change in the pharyngeal airway dimensions was found. It seems that the pharyngeal airway dimensions are formed and matured in the early periods of growth, and those years seem to be of high relevance to ensure the later physiological need of adequate airflow."[5]

Clinical Significance

The unexpected findings of Class II males having a larger airway than Class I males suggest that the constriction of airway may be in the transverse dimension, which was lost in this study due to the use of 2D cephalograms.[13] Kim et al. demonstrated that the transverse dimension of the airway is larger than the sagittal dimension in skeletal Class I and II children. [13] This suggests that the airway expands most in the transverse dimension with age as opposed to the sagittal dimension.[2]

On the contrary, it is also possible that the constriction may be anatomically elsewhere, such as in the nasal cavity. Future studies on incorporating frontal cephalograms or 3D CBCT may expose more valuable and comprehensive findings of narrowed airway in Class II subjects.

Conclusions

Class II Patients

1. Class II males had more airway width than Class II females at all ages, except at age 8 for 3A-3B and age 12 at 4A-4B. Class II males had a statistically greater 1A-1B measurement at age 7 (*P* = 0.020) and 13 (*P* = 0.017), 2A-2B measurement at age 7 (*P* = 0.070), 4A-4B measurement at age 13 (*P* = 0.021), 14

($P = 0.044$), and 16 ($P = 0.016$), 5A-5B measurement at age 8 ($P = 0.006$), 13 ($P = 0.030$), 14 ($P = 0.037$), 15 ($P = 0.007$), and 16 ($P = 0.000$), 6A-6B measurement at age 7 ($P = 0.042$), 8 ($P = 0.036$), 9 ($P = 0.008$), 11 ($P = 0.009$), 12 ($P = 0.019$), 13 ($P = 0.010$), 14 ($P = 0.002$), 15 ($P = 0.017$), and 16 ($P = 0.000$) than Class II females of the respective ages.

2. There was a statistically significant increase in 1A-1B in Class II females from 7 to 16 years of age ($P = 0.023$) of 5.436mm. There was a statistically significant increase in 5A-5B in Class II males from 7 to 16 years of age ($P = 0.003$) of 4.962mm.
3. We were able to reject null hypotheses #1 and #2.

Class I vs Class II Patients

4. Class I females at age 11 and 8 had a statistically greater 3A-3B ($P = 0.049$) and 5A-5B ($P = 0.018$) measurement, respectively, than Class II females at that age. On the contrary, Class II females at age 12 had a statistically greater 4A-4B ($P = 0.041$) measurement than Class I females at that age.
5. Class II males had a statistically greater 1A-1B measurement at age 9 ($P = 0.008$), 10 ($P = 0.025$), 13 ($P = 0.008$), and 14 ($P = 0.046$), 4A-4B measurement at age 7 ($P = 0.047$), 10 ($P = 0.012$), 11 ($P = 0.006$), 12 ($P = 0.016$), 13 ($P = 0.003$), 14 ($P = 0.003$), 15 ($P = 0.004$), and 16 ($P = 0.000$), 5A-5B measurement at age 13 ($P = 0.029$) and 16 ($P = 0.005$) than Class I males at the respective ages.

6. There was no statistical significant difference in change in airway with increasing age between Class I and Class II patients within each gender group at each respective age group.
7. We were able to reject null hypothesis #3.
8. We were unable to reject null hypothesis #4.

CHAPTER THREE

EXTENDED DISCUSSION

Limitations of Study and Recommendations for Future Studies

Since information is lost in the transverse dimension, the accuracy of 2D cephalograms as a diagnostic tool has been questioned in airway studies. With the advent of 3D imaging techniques, many studies have stated that CBCT and MRI have expanded diagnostic capacities, allowing volumetric analysis and accurate visualization of the airway while cephalograms are limited to measurements in the sagittal view.[5] According to Mislik et al., the pharyngeal airway is not a rigid structure and its dimensions are influenced by several factors, including positioning, muscle tone, respiration, duration of x-ray exposure, and mouth opening.[5] With this in mind, even a 3D radiograph does not account for the true clinical circumstances under which SDB may occur.[5] However, many argue that the transverse information provided by CBCT is the standard when studying the airway.

On the contrary, in a CBCT study comparing OSA to non-OSA patients, Ogawa et al. found that only the smallest cross-sectional airway area was found to be significantly different between the two groups.[8] This infers that the smallest cross-sectional area in the anterior-posterior direction is the dimension of highest clinical relevance.[5] Another study also demonstrated data collected by CT and MRI are difficult to compare due to the lack of standardized protocols defining the thickness, direction, and precise location of sections.[10]

Ultimately, a systematic review concluded that conventional lateral cephalograms are still a legitimate screening tool for pharyngeal airway obstruction.[11] Despite limitations, cephalograms provide critical measurements for airway and their low cost, minimal exposure to radiation, easy access, and standardization of measurements with high reproducibility allow orthodontists to routinely use this reliable tool to assess airway.[5,10,12,13] However, including CBCT measurements of both the sagittal and transverse dimensions of the airway will provide a more comprehensive perspective on the characteristics of airway changes with gender and increasing age in different skeletal patterns. While there will not be a database of longitudinal CBCT records due to the higher dose of radiation with CBCT than cephalograms, pre-treatment and post-treatment CBCT records will share valuable information of the possible changes in airway with different types of orthodontic treatment. Overall, the additional information provided by CBCT can be used to help clinicians better understand the airway in 3D.

Besides the use of 2D lateral cephalograms, there were other limitations to the study. Lack of medical history prevented exclusion of subjects with pre-existing airway issues. Additionally, a limited sample size of 38 patients does not provide a solid representation of the general population. Since one investigator collected the Class I airway measurements and another investigator collected the Class II airway measurements, comparing both values directly could have introduced error. Although the individual investigators had excellent agreement within their own measurements, they were not calibrated with one another. Lastly, the study used patients with predominantly mesofacial and brachyfacial face types.

REFERENCES

1. Ceylan I, Oktay H. A study on the pharyngeal size in different skeletal patterns. *American Journal of Orthodontics and Dentofacial Orthopedics*. 2017;108(1):69-75.

2. Kim Y-J, Hong J-S, Hwang Y-I, Park Y-H. Three-dimensional analysis of pharyngeal airway in preadolescent children with different anteroposterior skeletal patterns. *American Journal of Orthodontics and Dentofacial Orthopedics*. 2010;137(3):306.e1-306.e11. doi:10.1016/j.ajodo.2009.10.025.

3. Soheilifar S, Soheilifar S, Soheilifar S. Upper Airway Dimensions in Patients With Class II and Class I Skeletal Pattern. *Avicenna J Dent Res*. 2014;6(2):1-5. doi:10.17795/ajdr-23300.

4. Claudino LV, Mattos CT, de Oliveira Ruellas AC, Sant' Anna EF. Pharyngeal airway characterization in adolescents related to facial skeletal pattern: A preliminary study. *American Journal of Orthodontics and Dentofacial Orthopedics*. 2013;143(6):799-809. doi:10.1016/j.ajodo.2013.01.015.

5. Mislik B, Hanggi MP, Signorelli L, Peltomaki TA, Patcas R. Pharyngeal airway dimensions: a cephalometric, growth-study-based analysis of physiological variations in children aged 6-17. *The European Journal of Orthodontics*. 2014;36(3):331-339. doi:10.1093/ejo/cjt068.

6. Feres MFN, Hermann JS, Cappellette M Jr, Pignatari SSN. Lateral X-ray view of the skull for the diagnosis of adenoid hypertrophy: A systematic review. *International Journal of Pediatric Otorhinolaryngology*. 2011;75(1):1-11. doi:10.1016/j.ijporl.2010.11.002.

7. Kolo ES, Salisu AD, Tabari AM, Dahilo EA, Aluko AA. Plain radiographic evaluation of the nasopharynx: Do raters agree? *International Journal of Pediatric Otorhinolaryngology*. 2010;74(5):532-534. doi:10.1016/j.ijporl.2010.02.015.

8. Ogawa T, Enciso R, Shintaku WH, Clark GT. Evaluation of cross-section airway configuration of obstructive sleep apnea. *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology, and Endodontology*. 2007;103(1):102-108. doi:10.1016/j.tripleo.2006.06.008.

9. Pirilä-Parkkinen K, Löppönen H, Nieminen P, Tolonen U, Pääkkö E, Pirttiniemi P. Validity of upper airway assessment in children: A clinical, cephalometric, and MRI study. *The Angle Orthodontist*. 2011;81(3):433-439. doi:10.2319/063010-362.1.

10. Muto T, Yamazaki A, Takeda S. A cephalometric evaluation of the pharyngeal airway space in patients with mandibular retrognathia and prognathia, and normal subjects. *International Journal of Oral and Maxillofacial Surgery*. 2008;37(3):228-231. doi:10.1016/j.ijom.2007.06.020.

11. Major MP, Flores-Mir C, Major PW. Assessment of lateral cephalometric diagnosis of adenoid hypertrophy and posterior upper airway obstruction: A systematic review. *American Journal of Orthodontics and Dentofacial Orthopedics*. 2006;130(6):700-708. doi:10.1016/j.ajodo.2005.05.050.

12. Silva NNE, Lacerda RHW, Silva AWC, Ramos TB. Assessment of upper airways measurements in patients with mandibular skeletal Class II malocclusion. *Dental Press J Orthod*. 2015;20(5):86-93. doi:10.1590/2177-6709.20.5.086-093.oar.

13. Aboudara C, Nielsen I, Huang JC, Maki K, Miller AJ, Hatcher D. Comparison of airway space with conventional lateral headfilms and 3-dimensional reconstruction from cone-beam computed tomography. *American Journal of Orthodontics and Dentofacial Orthopedics*. 2009;135(4):468-479. doi:10.1016/j.ajodo.2007.04.043.

14. Ceylan I, Oktay H. A study on the pharyngeal size in different skeletal patterns. *American Journal of Orthodontics and Dentofacial Orthopedics*. 1995;108(1):69-75.

15. Indriksone I, Jakobstone G. The upper airway dimensions in different sagittal craniofacial patterns: a systematic review. *Stomatologija, Baltic Dental and Maxillofacial Journal*. 2014;16:1-9.

16. El H, Palomo JM. Airway volume for different dentofacial skeletal patterns. *American Journal of Orthodontics and Dentofacial Orthopedics*. 2011;139(6):e511-e521. doi:10.1016/j.ajodo.2011.02.015.

17. Joseph A, Elbaum J, Cisneros G, Eisig S. A Cephalometric Comparative Study of the Soft Tissue Airway Dimensions in Persons with Hyperdivergent and Normodivergent Facial Patterns. *International Journal of Oral and Maxillofacial Surgery*. 2004;56:1-5.

18. Martin SE, Mathur R, Marshall I, Douglas NJ. The effect of age, sex, obesity and posture on upper airway size. *European Respiratory Journal*. 1997;10(9):2087-2090. doi:10.1183/09031936.97.10092087.

19. Schendel SA, Jacobson R, Khalessi S. Airway Growth and Development: A Computerized 3-Dimensional Analysis. *YJOMS*. 2012;70(9):2174-2183. doi:10.1016/j.joms.2011.10.013.

20. Aboudara C, Nielsen I, Huang JC, Maki K, Miller AJ, Hatcher D. Comparison of airway space with conventional lateral headfilms and 3-dimensional reconstruction from cone-beam computed tomography. *American Journal of Orthodontics and Dentofacial Orthopedics*. 2009;135(4):468-479. doi:10.1016/j.ajodo.2007.04.043.

21. *Scaled Measurements From the AAOF Legacy Collection Images*. 2015:1-9.

22. *Quick Ceph Studio*. 3rd ed. San Diego, CA

23. Standring S, Gray H, Borley NR, et al. *Gray's Anatomy: the Anatomical Basis of Clinical Practice*. 40 ed. Elsevier 2008

24. David A Covell Jr PhD D, ed. AAOF Craniofacial Growth Legacy Collection. http://www.aaoflegacycollection.org/aaof_collection.html?id=UOGrowth.

25. Singh IJ, Savara BS. Norms Of Size And Annual Increments Of Seven Anatomical Measures Of Maxillae In Girls From Three To Sixteen Years Of Age*. *The Angle Orthodontist*. 1966.

26. Nunokawa J. April 2012. In: *Note Book*. Princeton: Princeton University Press; 1968.

27. Katyal V, Pamula Y, Martin AJ, Daynes CN, Kennedy JD, Sampson WJ. Craniofacial and upper airway morphology in pediatric sleep-disordered breathing: Systematic review and meta-analysis. Am J Orthod Dentofacial Orthop 2013;143:20–3.

28. Tourné LPM. Growth of the pharynx and its physiologic implications. Am J Orthod Dentofacial Orthop 1991;99:129–39.

29. Shusterman D. The effects of air pollutants and irritants on the upper airway. Proc Am Thorac Soc 2011;8:101–5.

30. Ogawa T, Venturin J, Clark G, Enciso R. Gender- and age-based differences in computerized tomographic measurements of the oropharynx. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod*. 2008 October; 106(4): 563–570.

31. Guttal K, Burde K. Cephalometric evaluation of upper airway in healthy adult population: A preliminary study. *J of Oral and Maxillofacial Radiology.* 2013. Vol I. Issue 2.

32. Daniel MM, Lorenzi MC, Leite C da C, Lorenzi-Filho G. Pharyngeal dimensions in healthy men and women. *Clinics*. 2007; 62(1):5-10.

33. McNamara JA Jr. A method of cephalometric evaluation. J Orthod 1984;86:449.

34. Battagel JM, Johal A, L'Estrange PR, Croft CB, Kotecha B. Changes in airway and hyoid position in response to mandibular protrusion in subjects with obstructive sleep apnea (OSA). *Eur J Orthod* 1999;21:363–76.

35. Arens R, McDonough JM, Corbin A, Hernandez M, Pack A. Linear Dimensions of the Upper Airway Structure During Development. *American Journal of Respiratory and Critical Care Medicine.* 2002;165:117-122.

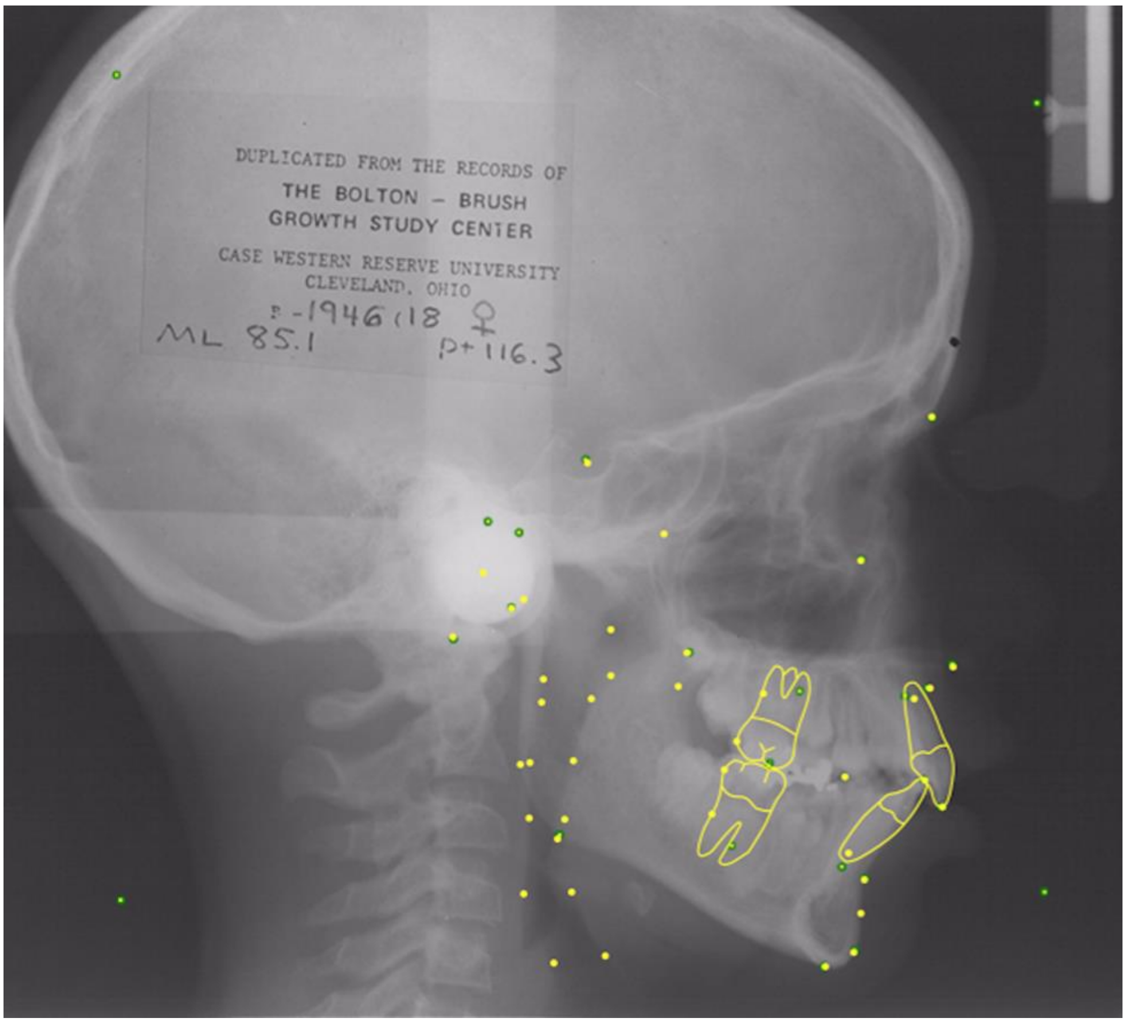
36. Jeans WD, Fernando DC, Maw AR, Leighton BC. A longitudinal study of the growth of the nasopharynx and its contents in normal children. Br J Radiol. 1981;54:117–121.

37. Haapaniemi JJ. Adenoids in school-aged children. J Laryngol Otol. 1995;109:196-202.

38. Woo, G. 2017. A Retrospective Lateral Cephalometric Growth Study of Sagittal Airway Changes (Unpublished master's thesis).

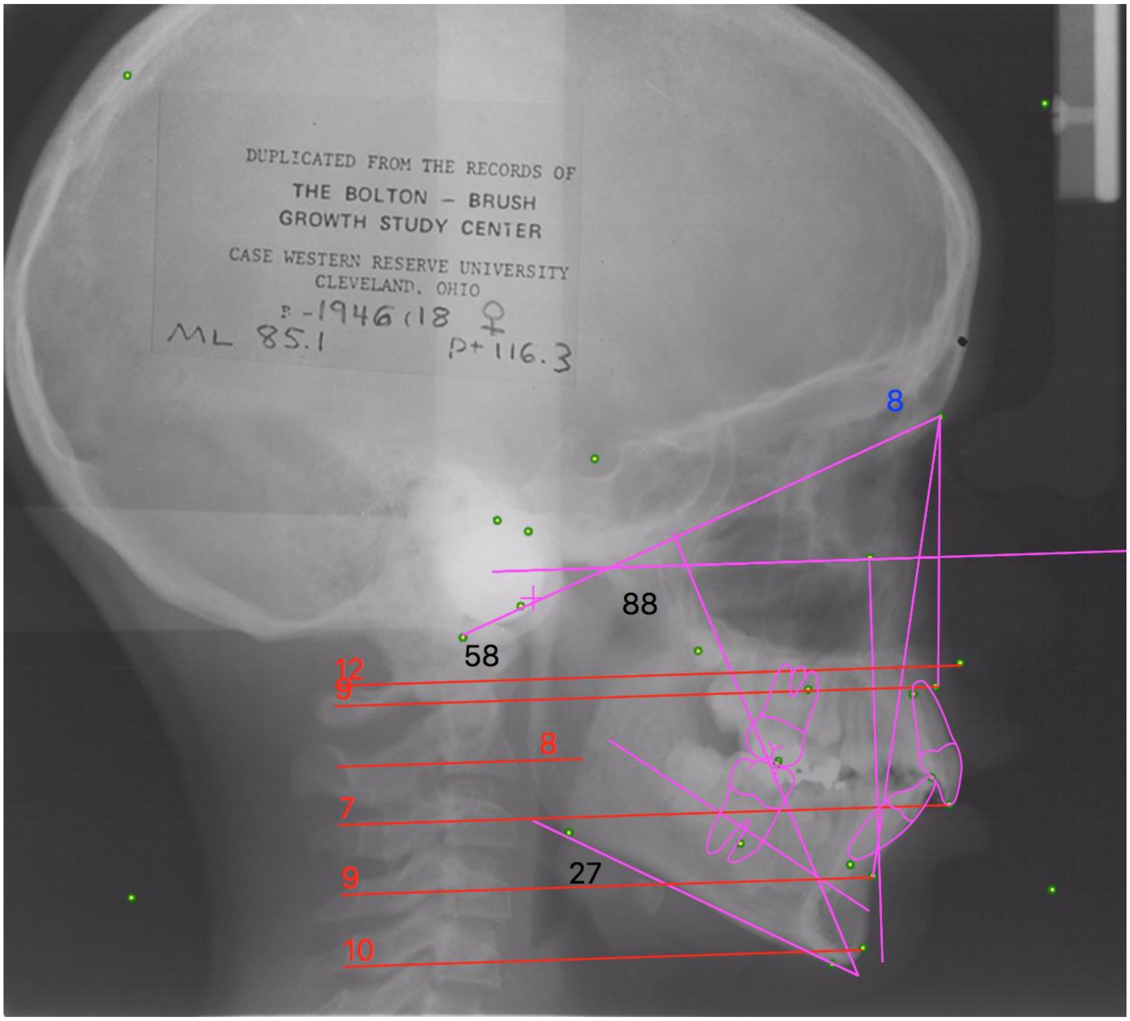
APPENDIX A

DIGITAL TRACING OF LANDMARKS ON SUBJECT 1946 AT AGE 11



APPENDIX B

SAGITTAL AIRWAY DIMENSION AND FACIAL TYPE MEASUREMENTS ON SUBJECT 1946 AT AGE 11



APPENDIX C

ESTIMATED MARGINAL MEANS AND 95% CONFIDENCE INTERVALS OF SAGITTAL AIRWAY DIMENSIONS ON PLANE 1-6

1A-1B				95% Confidence Interval	
Age	Gender	Mean	Std. Error	Lower Bound	Upper Bound
7	F	11.224	2.984	5.343	17.106
	M	19.585	2.598	14.465	24.705
8	F	13.827	2.984	7.946	19.709
	M	17.590	2.598	12.470	22.710
9	F	15.160	2.984	9.278	21.041
	M	19.287	2.634	14.095	24.478
10	F	15.717	2.984	9.836	21.599
	M	18.277	2.598	13.157	23.396
11	F	16.104	2.984	10.222	21.985
	M	18.331	2.598	13.211	23.451
12	F	14.660	2.994	8.760	20.559
	M	20.050	2.535	15.055	25.045
13	F	15.338	2.994	9.438	21.237
	M	21.975	2.620	16.812	27.138
14	F	16.395	2.984	10.514	22.277
	M	20.665	2.620	15.502	25.828
15	F	18.288	3.720	10.957	25.619
	M	17.243	3.118	11.099	23.387
16	F	16.660	2.984	10.778	22.541
	M	23.270	2.598	18.150	28.390

2A-2B				95% Confidence Interval	
Age	Gender	Mean	Std. Error	Lower Bound	Upper Bound
7	F	10.643	1.158	8.362	12.925
	M	14.406	1.008	12.420	16.391
8	F	11.847	1.158	9.566	14.128
	M	14.316	1.008	12.330	16.302
9	F	13.683	1.158	11.402	15.964
	M	14.868	1.022	12.855	16.882
10	F	14.101	1.158	11.820	16.382
	M	14.915	1.008	12.930	1.901
11	F	12.669	1.158	10.388	14.950
	M	14.548	1.008	12.562	16.533
12	F	12.713	1.161	10.424	15.001
	M	13.754	0.983	11.816	15.691
13	F	14.113	0.161	11.824	16.401
	M	14.775	1.016	12.773	16.777
14	F	13.987	1.158	11.697	16.259
	M	15.946	1.016	13.943	17.948
15	F	15.392	1.443	12.549	8.235
	M	15.751	1.209	13.368	18.134
16	F	13.964	1.158	11.683	16.245
	M	16.529	1.008	14.544	18.515

3A-3B				95% Confidence Interval	
Age	Gender	Mean	Std. Error	Lower Bound	Upper Bound
7	F	10.591	1.249	8.130	13.052
	M	12.539	1.087	10.397	14.681
8	F	12.625	1.249	10.164	15.086
	M	11.742	1.087	9.600	13.884
9	F	10.447	1.249	7.986	12.908
	M	12.028	1.102	9.856	14.200
10	F	11.205	1.249	8.744	13.665
	M	12.467	1.087	10.325	14.609
11	F	10.164	1.249	7.704	12.625
	M	12.459	1.087	10.317	14.601
12	F	11.263	1.252	8.794	13.731
	M	12.264	1.060	10.174	14.354
13	F	10.413	1.252	7.944	12.881
	M	13.106	1.096	10.945	15.266
14	F	11.568	1.249	9.107	14.028
	M	14.328	1.096	12.168	16.488
15	F	12.992	1.556	9.925	16.059
	M	14.176	1.304	11.606	6.746
16	F	12.418	1.249	9.958	14.879
	M	15.541	1.087	13.399	17.683

4A-4B				95% Confidence Interval	
Age	Gender	Mean	Std. Error	Lower Bound	Upper Bound
7	F	8.524	1.206	6.148	10.900
	M	10.292	1.049	8.224	12.360
8	F	8.230	1.206	5.854	10.605
	M	9.421	1.049	7.353	11.489
9	F	9.227	1.206	6.851	11.602
	M	11.072	1.064	8.975	13.169
10	F	9.290	1.206	6.914	11.666
	M	12.091	1.049	10.023	14.159
11	F	9.292	1.206	6.917	11.668
	M	12.083	1.049	10.015	14.159
12	F	12.100	1.209	9.717	14.483
	M	11.971	1.024	9.953	13.989
13	F	8.518	1.209	6.135	10.901
	M	12.650	1.058	10.580	14.751
14	F	9.571	1.206	7.196	11.947
	M	14.497	1.080	12.412	16.583
15	F	9.920	1.503	6.959	12.881
	M	13.789	1.259	11.307	16.271
16	F	10.228	1.206	7.852	12.604
	M	13.978	1.049	11.909	16.046

5A-5B				95% Confidence Interval	
Age	Gender	Mean	Std. Error	Lower Bound	Upper Bound
7	F	9.298	1.056	7.217	11.380
	M	12.746	0.919	10.063	13.687
8	F	9.934	1.056	7.852	12.015
	M	11.875	0.919	11.138	14.812
9	F	12.151	1.056	10.069	14.232
	M	12.975	0.932	11.138	14.812
10	F	12.311	1.056	10.230	14.393
	M	14.180	0.919	12.368	15.992
11	F	10.376	1.056	8.294	12.457
	M	15.232	0.919	13.511	17.135
12	F	13.775	1.059	11.687	15.863
	M	14.294	0.897	12.526	16.061
13	F	12.539	1.059	10.451	14.627
	M	16.069	0.927	14.242	17.897
14	F	11.976	1.056	9.894	14.057
	M	16.811	0.927	14.984	18.638
15	F	12.804	1.317	10.210	15.398
	M	16.138	1.103	13.964	18.312
16	F	12.789	1.056	10.707	14.870
	M	17.708	0.919	15.896	19.520

6A-6B				95% Confidence Interval	
Age	Gender	Mean	Std. Error	Lower Bound	Upper Bound
7	F	8.244	1.008	6.258	10.230
	M	12.649	0.877	10.919	14.378
8	F	8.647	1.008	6.661	10.633
	M	10.534	0.877	8.805	12.263
9	F	9.847	1.008	7.861	11.833
	M	11.591	0.890	9.838	13.345
10	F	9.573	1.008	7.586	11.559
	M	11.808	0.877	10.079	13.538
11	F	9.066	1.008	7.080	11.052
	M	12.523	0.877	10.793	14.252
12	F	9.618	1.011	7.626	11.611
	M	11.137	0.856	9.450	12.824
13	F	8.468	1.011	6.476	10.461
	M	14.228	0.885	12.484	15.972
14	F	9.680	1.008	7.694	11.667
	M	13.747	0.885	12.003	15.491
15	F	10.088	1.256	7.612	12.564
	M	14.125	1.053	12.050	16.200
16	F	9.816	1.008	7.830	11.802
	M	14.176	0.877	12.447	15.906

APPENDIX D

TOTAL FACE HEIGHT CHANGE BETWEEN AGES 7 AND 16

Patient	Location	Age	TFH	TFH Change
1946	Bolton	7	55.2	-0.6
		16	55.8	
2147	Bolton	7	61.2	10.0
		16	51.2	
2207	Bolton	7	60.1	9.1
		16	51.0	
2259	Bolton	7	54.7	2.1
		16	52.6	
2491	Bolton	7	62.2	5.6
		16	56.6	
2701	Bolton	7	57.4	-1.7
		16	59.1	
2739	Bolton	7	58.6	2.2
		16	56.4	
261	Bolton	7	54.5	9.6
		16	44.9	
2326	Bolton	7	60.3	0.4
		16	59.9	
2378	Bolton	7	61.0	6.1
		16	54.9	
3059	Bolton	7	49.5	-2.4
		16	51.9	
3345	Bolton	7	52.0	2.3
		16	49.7	
208	Burlington	7	65.6	1.1
		16	64.5	
482	Burlington	7	54.7	-0.2
		16	54.9	
717	Burlington	7	71.7	1.9
		16	69.8	
855	Burlington	7	61.5	4.1
		16	57.4	
183	Burlington	7	60.5	0.5
		16	60.0	

206	Burlington	7	66.2	0.1
		16	66.1	
257	Burlington	7	54.7	0.8
		16	53.9	
289	Burlington	7	59.3	-2.8
		16	62.1	
295	Burlington	7	57.4	2.6
		16	54.8	
863	Burlington	7	60.5	3.9
		16	56.6	
54	Denver	7	63.2	2.5
		16	60.7	
504	Denver	7	63.1	1.6
		16	61.5	
566	Denver	7	52.2	3.8
		16	48.4	
570	Denver	7	49.7	2.9
		16	46.8	
3711	Forsyth	7	51.7	0.0
		16	51.7	
3712	Forsyth	7	56.8	5.4
		16	51.4	
4012	Forsyth	7	60.4	2.8
		16	57.6	
15	Iowa	7	55.6	4.0
		16	51.6	
24	Iowa	7	59.6	0.1
		16	59.5	
19	Mathews	7	60.1	1.7
		16	58.4	
2000	Michigan	7	61.4	0.4
		16	61.0	
2101	Michigan	7	68.4	1.5
		16	66.9	
2257	Michigan	7	55.3	1.3
		16	54.0	
2392	Michigan	7	59.9	5.4
		16	54.5	

301	Oregon	7	60.5	2.8
		16	57.7	
33	Oregon	7	66.0	4.9
		16	61.1	